Technology Adoption in the United States: The Impact of Hospital Market Competition

ABSTRACT

Objectives: Technological innovation in medicine is a significant driver of healthcare spending growth in the United States. Factors driving adoption and utilization of new technology is poorly understood, however market forces may play a significant role. Vascular surgery has experienced a surge in development of new devices and serves as an ideal case study. Specifically, the share of total abdominal aortic aneurysm (AAA) repairs performed by endovascular aneurysm repair (EVAR) increased rapidly from 32% in 2001 to 65% in 2006 with considerable variation between states. This paper hypothesizes that that hospitals in competitive markets were early EVAR adopters and had improved AAA repair outcomes.

Methods: The Nationwide Inpatient Sample (NIS) and linked Hospital Market Structure (HMS) data was queried for patients who underwent repair for non-ruptured AAA in 2003. In HMS the Herfindahl Hirschman Index (HHI, range 0-1) is a validated and widely accepted economic measure of competition. Hospital markets were defined using a variable geographic radius that encompassed 90% of discharged patients. Bivariable and multivariable linear and logistic regression analyses were performed for the dependent variable of EVAR use. A propensity score-adjusted multivariate logistic regression model was used to control for treatment bias in the assessment of competition on AAA-repair outcomes.

Results: A weighted total of 21,600 patients was included in the analyses. Patients at more competitive hospitals (lower HHI) were at increased odds of undergoing EVAR vs. open repair (Odds Ratio 1.127 per 0.1 decrease in HHI, P<0.0127) after adjusting for patient demographics, co-morbidities and hospital level factors (bed size, teaching status, AAA repair volume and ownership). Competition was not associated with differences in in-hospital mortality or vascular, neurologic or other minor post-operative complications.

Conclusion: Greater hospital competition is significantly associated with increased EVAR adoption at a time when diffusion of this technology passed its tipping point. Hospital competition does not influence post-AAA repair outcomes. These results suggest that adoption of novel technology is not solely driven by clinical indications, but may also be influenced by market forces.

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GLOSSARY LISTING

AAA = abdominal aortic aneurysm

CBO = Congressional Budget Office

CEA = cost effectiveness analysis

CER = comparative effectiveness research

EVAR = endovascular aneurysm repair

FDA = Food and Drug Administration

HCUP = Healthcare Cost and Utilization Project

HHI = Herfindahl Hirschman Index

HMS = Hospital Market Structure

NIS = Nationwide Inpatient Sample

US = United States

INTRODUCTION

The United States is a global leader in healthcare innovation. In 2001, Victor Fuchs and Harold Sox published the most widely cited list of thirty major innovations in medicine.[1] Selected medical devices, diagnostic tools, drugs and other therapeutics were identified based on the frequency of subject-related publications in the Journal of the American Medical Association and New England Journal of Medicine between 1976 and 2001. Impressively, the vast majority originated in the United States including magnetic resonance imaging and computed tomography scanning, balloon angioplasty (through collaborations with Switzerland), mammography, coronary artery bypass graft surgery, cataract extraction and lens implants, among others. These and other innovations have collectively improved the quality of life for hundreds of millions of individuals around the world and have had an integral role in the vitality of domestic and global economies.

Innovation, however, is expensive. Between 1965 and 2005, per-capita healthcare expenditures in the US increased nearly six-fold.[2] In a 1996 survey of 46 of the world's leading health economists, 81% agreed that technological changes in medicine were the primary reason for the rise in healthcare spending.[3] Indeed, this has been supported by numerous health economics studies. In his 1992 study, Joseph Newhouse estimated technological advancements in medicine could account for greater than 65% of growth in real health care spending per capita between 1940 and 1990.[4] In 2008 the Congressional Budget Office published a report on growth in healthcare spending in the US.[2] They estimated that that technology-related changes in medical practices are the major driver of healthcare spending and can account for up to 62% of growth in real health spending per capita. Recent estimates are more conservative and suggest that medical technology may account for 27-48% of spending growth.[5]

The benefit and costs of investing in medical innovation have been debated extensively.[6] In a 2001 study published in the journal Health Affairs, Mark McClellan and David Cutler present five case studies in support of their argument that technology investment is worthwhile. For example, they found that for every one dollar spent on the development of cardiac catheterization technology, the value gain was seven dollars based on data extracted from Medicare claims records. Value was measured monetarily; each year of life expectancy gained was valued at $100,000.

However, adoption behaviors and technology diffusion are not always incentivized to select for “high-value” innovation. There continue to be significant time-lags between the discovery of proven, life-saving interventions, such as initial treatment of myocardial infarction with aspirin, and widespread implementation of this knowledge.[7] Yet new technologies such as robotic surgery have been adopted rapidly despite their tremendous cost, lack of additional insurance reimbursement for robotic costs, and limited efficacy data.[8] In 2009, up to 85% of radical prostatectomies were performed robotically.[8] The addition of a single robot per 100,000 men in a hospital market was associated with a 30% increase in the rate of total radical prostatectomies.[8] Coronary computed tomography angiography was introduced in 2004 and experienced immense popularity and uptake despite lackluster clinical evidence and poor cost-effectiveness.[9]

Indeed, adoption behaviors in medicine are nuanced. Donald Berwick described three “clusters of influence”. The first cluster is perceived benefit of change and features of the technology or the device itself including “trialability” and “observability”.[7]

Second, individuals can be classified into five categories based on their adoption practices: innovators, early adopters, early majority adopters, later majority adopters and laggards.[10] Third, contextual factors such as communication, incentives, leadership and management all play a critical role in determining how innovation is perceived and integrated into an existing practice or setting.

Additional factors have been associated with adoption of new technology.[11] These include adopters' perceptions of the adoption behavior of individuals around them. Awareness about new technology often occurs through impersonal sources such as journals, meetings and conferences. Personal discussions with colleagues may be more important closer to the time of actual adoption.[12] In surgery, learning how to use a new technology requires the adopter to incur additional costs such as cost of training through didactic courses or animal models and retrofitting new technology into older operating rooms. Therefore, technologies that are lower cost to implement may be adopted faster. Adopters assess expected monetary gains. Ladapo et al demonstrated that hospitals with higher operating margins are significantly more likely to adopt CT angiography.[9] In the case of robotic prostatectomy, hospitals operating in regions where a large proportion of surrounding hospitals already had robots were more significantly more likely to adopt robotic technology.[8] Hospitals compete amongst each other for surgical volume, therefore adoption of highly marketable technologies may be a necessity for financial well-being.[13]

Purpose of inquiry

The focus of this paper is the investigation of factors associated with the adoption of new medical technology. The literature, as summarized above, suggests numerous factors are at play. However, market factors may have a significant role. The hypothesis tested here posits that hospitals existing in more competitive markets are more likely to adopt new medical technology. Hospitals in competitive markets may seek to distinguish themselves from their competitors by offering new procedures or services, especially when those provide distinct differences in patient experiences. The ability to market new technology may also be a mechanism for building patient volume and sustaining clinical income. Given disparate adoption behaviors, this paper also investigates the impact competition may have on outcomes for patients. It is beyond the scope of this paper to determine whether competition is associated with the adoption and utilization of all types of medical innovation, therefore a case-study approach focusing on the adoption of a new method for repair of abdominal aortic aneurysms was used to answer the questions posed above.

Vascular surgery has experienced a surge in surgical device innovation since the late 1990s, predominantly in the development of endovascular technology. In 1999 endovascular aneurysm repair (EVAR) was approved by the Food and Drug Administration (FDA) as a novel technology for minimally invasive abdominal aortic aneurysm (AAA) repair. The primary goal of AAA repair is prevention of aneurysmal rupture, which is associated with a mortality rate approaching 80%.[14] In the case of EVAR, the choice between bilateral groin incisions vs. midline laparotomy for traditional open AAA repair may attract patients seeking a less invasive treatment. Currently, EVAR is the most common method of repair for non-ruptured AAA in the US. This technology was identified as an ideal case study for the assessment of whether competition between hospitals is associated with greater technology adoption and utilization and what impact competition has on patient outcomes.

Similar to robotic prostatectomy, EVAR was rapidly adopted and between 2001 and 2007 its utilization increased by 105%.[15] Recent data, however, suggests that there are geographic differences in EVAR utilization between states.[16] This raises concern about appropriate use of technology and has implications for health care spending growth. Data from the EVAR 1 trial, a large randomized control trial conducted in the United Kingdom, demonstrated that total average cost of aneurysm-related procedures for EVAR patients during eight years of follow up is $4,568 (USD) more than open repair patients, while demonstrating no significant improvement in long-term aneurysm-related mortality between EVAR and open AAA repair.[17] These and other data provide impetus to understand what factors drive adoption of a potential costly technology.

Prior literature on factors associated with adoption and utilization of EVAR is limited. A 2012 retrospective analysis of the California Office of Statewide Health Planning ad Development inpatient database found that among 33,277 patients with AAA, 35% underwent EVAR.[18] Significant predictors of EVAR utilization included calendar year, older age, male gender, non-ruptured status, teaching hospital and higher volume hospital. The authors also noted found that the rate of EVAR between 2001 and 2008 occurred primarily in areas of California without large academic medical centers.

In this paper, the degree of competition between hospitals in pre-defined markets is quantified using the Herfindahl Hirschman Index (HHI). HHI is a measure of hospital market competition.[19] A detailed description of this index and its calculation are presented in the methods section. In general, HHI is a widely accepted and validated measure of competition used by the Department of Justice, Securities and Exchange Commission, and other governing organizations to determine the degree of competition in various commercial markets.[20] For example, in 2008 the Department of Justice used this index to rule that a proposed merger between UnitedHealth Group and Sierra Health Services Inc. would substantially reduce competition (increase in HHI of 0.1625) in the health insurance market in Nevada .[21]

In summary, the specific aims of this paper are to 1) describe EVAR utilization trends between 2001 and 2007; 2) determine whether hospitals operating in more competitive markets, as quantified by HHI, have greater utilization of EVAR versus traditional open-AAA repair; and 3) assess whether greater competition leads to decreased in-hospital mortality, length of stay and post-operative complications, consistent with the economic notion that competition promotes improvement in productivity, outcomes and lowers costs.

METHODS

Data sources

The 2001-2007 Nationwide Inpatient Sample (NIS) and 2003 Hospital Market Structure (HMS) files published by the Healthcare Cost and Utilization Project (HCUP) were used to assess the impact of hospital market competition on EVAR adoption and AAA-repair outcomes. NIS is the nation's largest all-payer inpatient database that provides a twenty percent stratified sample of hospital admissions.

In the HMS files, hospital competition is quantified using HHI. Each hospital within a market has a share of the market, as defined by the number of discharges from that hospital divided by the total number of discharges from all hospitals in the market. HHI is calculated as the sum of squared market shares for all hospitals existing in markets defined by geopolitical boundaries, fixed radius, variable radius and patient flow according to methods described by Wong et al.[19] It ranges from approaching zero (highly competitive) to one (monopoly). HHI not only reflects the number of competitors within a market, but also the equity of distribution of market share. More competitors lead to a more competitive market, but more importantly balanced market shares among competitors also have a strong effect on competition. A sample calculation of HHI is provided in Figure 1.

HMS files are published for linkage with 1997, 2000 and 2003 NIS data. The 2003 data file was selected in order to analyze the impact of hospital market competition on EVAR adoption after EVAR was approved by the FDA in late 1999 and before it surpassed utilization of open-repair in 2004.[15] 652 out of 994 hospitals surveyed in the 2003 NIS had HHI data and were included in our analysis. Entire hospital markets were not excluded if an individual hospital in the market had missing

HHI. A hospital's HHI incorporates the presence of all hospitals in the market, even if a single hospital in that market does not have its own HHI value.

Patient level observations in NIS were supplemented with state-level data obtained from The Henry J. Kaiser Family Foundation State Health Facts online database and Dartmouth Atlas of Health Care online database to account for variations in malpractice claim payments, number of vascular surgeons and total health expenditures per state.[22, 23]

Study design

Patients who underwent repair for non-ruptured AAA (ICD-9CM 441.4, 441.9) by open or endovascular technique (ICD-9CM 38.34, 38.44, 38.64, 39.71) in 2003 at hospitals for which HHI data was available were included in our analysis (weighted N= 21,600). Hospital markets were defined using a variable geographic radius that encompassed 90% of discharged patients. This market definition accounts for the fact that hospitals do not compete within confined geographic boundaries. The same cohort of patients was queried for post-AAA repair outcomes including in-hospital death, length of stay, vascular complications (including graft complication, embolism or infection)and major post-operative complications as defined by the National Surgical Quality Improvement Program (NSQIP).[24]

Statistical analysis

EVAR and open-AAA repair data was plotted between 2001 and 2007 to analyze usage trends. State-level EVAR adoption for hospitals performing greater than ten

AAA-repairs was plotted for each year between 2001 and 2007 using EpiInfo™ software published by the Centers for Disease Control.[25]

Bivariable logistic regression analyses was conducted to determine the association between hospital competition, and potential confounders, and the outcome of EVAR adoption in 2003. State-level variables, including total number of malpractice claims, average malpractice claim payment, average number of vascular surgeons, and average health expenditures per state, were included to control for potential confounders considered in previous studies.[15] Patient co-morbidities were controlled using the Elixhauser method.[26] Covariates that were significant in bivariate analysis ($P < 0.05$) were entered into a multivariable logistic regression model with backwards selection for the dependent variable of EVAR use. Statistical significance was defined by a type I error threshold of 0.05, corresponding to 95% confidence intervals.

Propensity score-weighted outcome models were used to control for treatment bias in the assessment of hospital competition, as measured by HHI, on post-operative AAA-repair outcomes in 2003. Propensity scores were first generated using a multivariable logistic regression model for the dependent variable of EVAR repair using covariates (patient demographics, co-morbidities, hospital and state-level factors) significant in bivariate logistic regression analysis ($P<0.10$) .[27] The inverse of each score was subsequently used to assign a weight to each patient to balance their treatment probability. Using propensity-score weighted data, individual multivariable logistic regression models were generated to study associations between hospital competition and post operative outcomes of in-hospital mortality, duration of hospital stay, vascular complication (graft embolism, infection or other complication) and standard post-operative complications as defined by NSQIP. Potential confounders considered earlier were adjusted for in each model. All data linkages and statistical analyses were conducted using SAS version 9.2 (SAS Institute, Cary, NC).

RESULTS

EVAR utilization trends

National EVAR adoption increased rapidly between 2001 and 2007: 33.61% (±1.96) of total non-ruptured AAA-repair procedures were performed by EVAR in 2001 as compared to 72.20% (±1.14) in 2007. EVAR surpassed open-AAA repair with 52.28% (±1.87) utilization nationwide in 2004 (Figure 2). Geographic variation in percent EVAR adoption between 2001 and 2007 was also observed (Figure 3). The total number of AAA-repair procedures conducted between 2001 and 2007 did not significantly increase. Approximately 39,500 total non-ruptured AAA repairs were performed in 2001 as compared to 38,972 in 2007.

Predictors of EVAR utilization

In 2003, a weighted total of 21,600 patients underwent AAA-repair at hospitals for which HHI data was available. Of these patients, 48.52% (±2.07) underwent EVAR. On average, EVAR patients were older (73.55 vs. 71.59, $P<0.0001$) and a higher percentage were male (83.34% vs. 76.30%, $P<0.0001$). There were significant differences in patient co-morbidities including higher incidence of congestive heart failure, peripheral vascular disease, chronic pulmonary disease, renal failure, coagulopathy, weight loss, fluid and electrolyte disorders, chronic blood loss anemia, alcohol abuse and psychoses in open-AAA repair patients. There was significantly higher incidence of uncomplicated diabetes mellitus and solid tumors in EVAR patients (Table 1-3). There were no significant differences in race or socioeconomic status.

EVAR patients underwent their procedure at more competitive hospitals with lower HHI (mean HHI = 0.15 vs. 0.19, $P<0.0004$) and hospitals with higher AAA-repair volume (mean annual AAA-repair cases = 59.63 vs. 41.26, P <0.0001). EVAR patients were also more likely to have undergone procedures at private, urban and teaching hospitals (Table 1-3). State-level factors were not significantly associated with EVAR use, including total number of malpractice claims, average malpractice claim payment, average number of vascular surgeons per state and average health expenditures per state.

In multivariable analysis the effect of hospital competition on the dependent variable of EVAR use remained significant (OR 1.127 per 0.1 decrease in HHI, CI: 1.102, 1.154, P<0.0127) after adjusting for age, gender, co-morbidities, admission status, and hospital location, ownership and AAA-repair volume (Table IV). Total AAA repairs per hospital remained significantly associated (OR 1.008, CI: 1.005, 1.011, P<0.0001) with EVAR adoption as did elective admission status (OR 1.704, CI: 1.272, 2.282, P<0.0004). Older patients remained at increased odds of undergoing EVAR (OR 1.041, CI: 1.032, 1.051, P<0.0001) as did males (OR 1.631, CI:1.379, 1.931, P<0.0001). Patients with diabetes or solid tumors were more likely to undergo EVAR, but patients with a number of other significant co-morbidities, including peripheral vascular disorders, coagulopathies, fluid and electrolyte disorders, deficiency anemias, solid tumors, and congestive heart failure were less likely (Table 4).

Propensity score-weighted outcome models were used to control for treatment bias in the assessment of competition on AAA-repair outcomes. Covariate balancing between EVAR and open-AAA repair patients was confirmed using bivariate logistic regression analysis (Table 5). The average in-hospital mortality for EVAR patients was 2.00% (±0.51) as compared to 4.48% (±0.38) for open-AAA repair patients. Open repair patients were hospitalized longer (mean length of stay = 9.23±0.18 days) and had a higher frequency of post-operative myocardial infarction (MI), cardiac complications, pulmonary embolism, major neurological complication (cerebral vascular accident or coma) and minor complications. EVAR patients, however, had greater frequency of vascular complications (9.72% ±4.23).

Multivariable logistic regression analysis in the propensity-weighted outcome model revealed that hospital competition was not significantly associated with in-hospital mortality, length of stay, or vascular, cardiac, neurologic or other minor post-operative complications following open-AAA repair or EVAR. Patients who underwent either open-AAA repair or EVAR at less competitive hospitals (higher HHI) had decreased odds of post-operative myocardial infarction (MI) (OR 0.048, 95% CI: 0.003, 0.699, $P<0.0263$) after adjusting for AAA-repair procedure type, patient age, elective admission status, hospital teaching status, and patient co-morbidities.

DISCUSSION, CONCLUSION AND SUGGESTIONS FOR FUTURE WORK

Numerous factors are associated with variation in the adoption of new technology. This paper investigates the impact of competition between hospitals on adoption behavior and patient outcomes using a case study of EVAR technology, which was introduced in 1999 as a revolutionary new technique for repair of abdominal aortic aneurysms.

This paper describes a novel association between greater hospital competition and increased EVAR adoption. In 2003, when EVAR was not the predominant technique of AAA-repair, more competitive hospitals were at significantly increased odds of utilizing EVAR. This held true after adjusting for differences in patient demographics, co-morbidities, and hospital-level factors. This paper also confirms historical trends in EVAR utilization between 2001 and 2007, and using choropleth maps demonstrates that there is geographic variation in EVAR utilization across time. As has been confirmed by numerous studies, EVAR is now the most common AAA-repair method.[15, 28, 29]

While competition in non-healthcare industries typically promotes improvement in quality of goods or services and leads to decreased costs, greater competition between hospitals was not significantly associated with reduction in in-hospital mortality, length of stay, or most major or minor post-operative complications after AAA-repair. Patients who underwent AAA-repair at more competitive hospitals were at increased odds of post-operative MI.

The role of competition

The association between greater hospital competition and greater EVAR adoption is not surprising. Several potential mechanisms may explain this association. Competitive hospitals are likely composed of physicians who seek to distinguish themselves through innovation or early adoption of new technology. Competitive hospitals may also have greater resources, both monetary and physical, facilitating early adoption behavior. In the case of EVAR, secondary competitive gains can be achieved. Adopting new technologies like EVAR allows hospitals to distinguish themselves as centers of innovation. This is a powerful marketing tool. Competitive hospitals also stand to benefit from supplementary revenue procured from increased utilization of imaging services, rehabilitation providers and expertise from vascular medicine. Additionally, there is evidence to suggest that decision-making at the institutional level is arbitrary in nature, allowing competition to have a stronger effect than it may otherwise have. A case analysis of the decision making process involved in the adoption of EVAR by Canadian academic health centers found that surprisingly few stakeholders are involved. Decisions in two academic centers were largely based on perceived benefit to patient outcomes, improved safety and surgeons' desire to innovate.[30]

In this paper, EVAR was used as a case study to determine whether market forces influence adoption behaviors. The trends and findings presented here are consistent with adoption behaviors in other areas of medicine and surgery.[7, 9, 12, 31-35] For example, hospitals functioning in more competitive markets were more likely to adopt laparoscopic colectomy for colon cancer resection between 2002 and 2007.[35] A 0.10 increase in HHI, or movement towards monopoly, was associated with a lower likelihood of undergoing laproscopic colectomy. The same increase in HHI was also associated with a 1.6% higher price for laparoscopic procedure, suggesting competition may decrease costs. Non-profit hospitals in more competitive markets were more likely to adopt radioisotope technology for nuclear medicine in the 1970s.[36] Fertility clinics operating in competition markets offered new intracytoplasmic sperm injection technology earlier than clinics in less competitive markets.[37] Competition has also been associated with duplication of hospital services within a geographic region. A 1972 survey of 3,584 community hospitals found that institutions surrounded by a greater number of other hospitals increased the availability of mammography, emergency services, cobalt therapy, heart surgery and cardiac catheterization facilities. This suggests that hospitals may invest in expensive facilities in order to compete with surrounding hospitals for greater patient volume.[38] However, other studies suggest competition has the opposite effect. Greater hospital competition has also been inversely associated with adoption of 64 slice computed tomography scanners.[9] This contradicts the traditional economic notion that competition should improve innovation and diffusion of technology. The study by Ladapo et al did not report CT ownership for 20% of hospitals. Of those excluded, the majority were for-profit hospitals that may have been more susceptible to market competition pressures.

Factors beyond hospital competition

Innovation in medicine is largely motivated by the opportunity to improve quality of care and improve outcomes for patients. Therefore, it was anticipated that clinical indications might also explain EVAR adoption trends. Indeed, prior studies have attributed variation in EVAR utilization to geographic differences in the prevalence of diabetes, vascular disease, and chronic obstructive pulmonary disease with the premise that EVAR is reserved for sicker patients.[15] This paper demonstrates that patients with diabetes and solid tumors are more likely to undergo EVAR as are older patients who may be considered higher surgical risk. However, high risk patients with multiple other co-morbidities including peripheral vascular disorders, coagulopathies, fluid and electrolyte disorders, deficiency anemias, solid tumors, and congestive heart failure were significantly less likely to undergo EVAR. This may suggest EVAR was being adopted without consideration of its intended demographic. In 2003, however, EVAR was still not widely adopted. Surgeons with relatively little EVAR experience may have initially employed this technology in healthier patients who had fewer co-morbidities.

EVAR adoption was not associated with patient demographics including race and socioeconomic status. It is conceivable that hospitals operating in states that have stricter malpractice laws or a greater density of vascular surgeons may be more likely to adopt the new technology. However variation in average state malpractice claims, and average number of vascular surgeons per state was not associated with greater EVAR utilization, confirming previously published data.[15] Patients admitted electively were more likely to undergo EVAR. This may be attributed to increased time surgeons needed to evaluate patients and determine anatomical suitability during these early years of EVAR adoption.

Other hospital-level factors including bed size, location and ownership did not significantly predict EVAR adoption with the exception of hospital AAA-repair volume. Hospitals with greater surgical volume may benefit from greater expertise in the field that permits early adoption behavior. Hospitals with more experience in EVAR repair may also have additional resources and funding to adopt new technology.

Implications of hospital competition

As a driver of EVAR adoption, hospital competition has important implications for social welfare, hospital costs and health policy. Ideally, competition between hospitals should improve quality of care and patient outcomes. In one of the early studies investigating this association, retrospective analysis found that hospital competition led to lower rates of adverse outcomes in non-rural elderly Medicare beneficiaries hospitalized for heart disease treatment after 1990.[39] In this paper, associations between greater hospital competition and AAA-repair outcomes including in-hospital mortality, length of stay, and NSQIP complications were assessed. Consistent with the economic notion that competition improves the quality of goods and services, it was anticipated that greater competition would have a comparable effect on measures of social welfare. Using propensity score weighted multivariable analysis, competition was found to neither improve nor worsen these outcomes with the exception of post-operative MI as patients at more competitive hospitals had higher risk of post-operative MI. There may have been unknown factors associated with a higher risk of MI in more competitive hospitals, such as referral of more complex patients to larger hospitals, which was unable to be control for in this analysis.

The study of competition and its effect on patient outcomes was limited to 2003 when EVAR adoption was still in an early phase of adoption. Many vascular specialists were still performing EVAR in low volumes. Their limited experience with this new technology may have modified the expected relationship between increased hospital volume and improved AAA-repair outcomes. Indeed, outcomes from early EVAR trials may have reflected the experience of expert surgeons who were pioneers in EVAR development.

Competition and cost of EVAR

Traditional economics principles support the association of greater competition among providers leads to lower cost for consumers. However, in health care, evidence suggests that competition may have no impact on cost or may even increase costs. Greater competition is associated with higher hospital gross charges for appendectomies, carotid endarterectomies, bariatric operations, radical prostatectomies, and pyloromyotomies.[40] In an editorial published in the Harvard Business Review, health economist and health policy expert Michael Porter argues that competition is the “root problem with US health care performance”.[41] Specifically, competition in healthcare has not increased value for health care consumers. Data from the EVAR1 trial in the United Kingdom estimates that during eight years of follow up, the total average cost of aneurysm-related procedures for EVAR patients in the United Kingdom is $4,568 US more than it is for open-repair patients.[17] It is concerning, then, that competition between hospitals is driving adoption of a costly technology that may not have significantly better outcomes for patients.

Vascular surgeons are not strangers to surgical innovation. Technology adoption is multi-factorial, but with evidence that competition may increase these practices, there is increasing concern about responsible acquisition and use of technology, especially in light of ongoing fiscal concerns.[16] While some technologies such as EVAR prove to be beneficial, many other technologies do not demonstrate significant clinical benefit or are not cost effective. Leaders in vascular surgery should acknowledge the impact of non-clinical factors such as hospital competition as they guide the development and implementation of future vascular technology.

Beyond EVAR

These data provide insight into adoption behaviors surrounding new technology in the medical industry. Specifically, medical device adoption is subject to intense market forces. Hospitals and providers compete with one another for patients and are incentivized to adopt highly marketable technologies in order to attract greater patient volume. Consideration of added value of a new device, procedure, or drug is frequently overlooked. There is evidence to suggest this is the case for technologies such as EVAR and robotic prostatectomy. More concerning is the fact that new technology may change the clinical indications for a procedure that has not been previously demonstrated; since the introduction of robotic prostatectomy the rate of total prostatectomies performed in the US has increased substantially. [13] In this paper, the total number of AAA-repair procedures has remained constant over time, despite the introduction of EVAR.

The current state of health care delivery is unsustainable if healthcare spending continues to increase at the same rate. Moderation of future spending may be achieved through reform efforts that call for more selective regulation and screening of new innovations. Competition should not be stifled, but rather incentives should be aligned to ensure competition is not a “zero-sum” proposition. This may be achieved through comparative-effectiveness and cost-effectiveness studies. At its core, comparative effectiveness research (CER) seeks to compare health care treatments for the same indication to determine which works best, for whom, and under what circumstances. Cost effectiveness analysis (CEA) allows for comparison between different treatments while also taking into consideration differences in cost. By integrating cost data, CEA can be used to assign value to comparator drugs, treatments, devices or services.

Because treatment outcomes are assessed using a common unit, it allows for comparisons to be made across all healthcare interventions regardless of indication. CEA provides decision makers with an objective and efficient way of understanding what interventions are most beneficial in the setting of limited health care resources.[42]

To this end, regulation agencies such as the Food and Drug Administration may require these studies as part of a new medical device application. Notably, there have been several attempts to formally use CEA as one of many criteria for determining reimbursement coverage for new technology. In 1989, a CMS proposal for CEA met with resistance and was never adopted.[43] This occurred during a time of relative economic prosperity in the U.S. and thus the pressure to adopt mechanisms to control health care costs were not as prominent as they are now. In 2003, the Medicare Modernization Act (MMA) established its support for comparative effectiveness research but with important caveats, namely the prohibition of formal cost-effectiveness analyses or the use of CER for mandating national standards of clinical practice.[44] However, the act permitted private payers to exercise their own judgment when assembling drug formulary lists, thereby increasing potential for use of CEA analysis. In 2009, Title VIII of the American Recovery and Reinvestment act authorized $1.1 billion for clinical effectiveness research, but again with no explicit endorsement of cost analysis.[44]

Perhaps the greatest obstacle to CEA has been the lack of public support and fear that cost-analyses will lead to rationing of care. Most Americans do not recognize CEA as a way to promote value; rather it is primarily viewed as a cost-containment maneuver.[44] There is a widespread belief that physicians and individuals, not government, should make treatment decisions and fear that CEA will further impede personalized medicine initiatives.[42, 45] This dissent is particularly vehement among the elderly and patients with chronic illnesses.[46] Unfortunately, many of these patients are recipients of expensive care that yields only incremental benefit. The United States is a leader in health care innovation and Americans have a fondness for new technology. Therefore cost-analyses are perceived as adding further insult to injury by limiting public access to novel treatments.[47]

These obstacles aside, future health reform should be targeted towards aligning incentives in new technology approval and adoption, especially in the context of competitive behavior between hospitals.

Limitations

This study has several limitations. The impact of hospital competition on EVAR adoption and outcomes was analyzed only in 2003 due to the availability of the Market Structure files at the time of analysis. However, 2003 was an appropriate year to analyze this association because EVAR was still in the early phases of adoption. While HHI is a validated measure of competition, it is not perfect. HHI calculations do not account for hospital networks, consolidations or partnerships. The market definitions we used may not account for large centers that attract patients nationwide. Additionally, HHI data was not available for hospitals from nine states. According to HCUP officials, data omission was random in nature and excluding these hospitals would not introduce bias into the analysis. Finally, there are a number of factors which may be associated with technology adoption that were unable to be accounted for including, but not limited to, hospital operating margins, presence or absence of ancillary hospital services, physician reimbursement schemes, provider age and training experience, variation in regional regulations for technology adoption, hospital access to capital. Many of these factors are either not quantified or not available. Surgeons may also have a preference for adoption of EVAR versus utilization of standard open repair. This could not be accounted for in this analysis. It is a difficult variable to quantify but nonetheless an important one to acknowledge. Despite these limitations, this analysis linking hospital competition with greater early EVAR utilization provides important insights into the adoption of medical technology.

Suggestions for Future Work

This study was limited to the assessment of competition in the adoption of EVAR. Future studies should investigate the role of market forces, such as competition, in the adoption of other technologies that have exhibited a similarly rapid rate of adoption and diffusion. While the NIS is the largest all-payer database in the United States, it is a stratified sample and does not capture all hospital discharges. This study may benefit from validation using additional datasets that overcome the limitations of the NIS. As mentioned, HHI is also not a perfect quantitative measure of hospital competition. Therefore investigation of new and more comprehensive metrics that account for its limitations previously outlined should be pursued. Additionally, competition exists in all aspects of healthcare. Future studies may consider using the Herfindahl Hirschman Index or a comparable measure to quantify the extent of competition in these different realms. Our group is currently investigating the role of competition between transplant centers in donor kidney allocation. Finally, further analysis is merited to better understand how competition affects patient outcomes over time. The analysis presented here was limited to one year, whereas competition may influence these metrics of social welfare over time.

SUMMARY

This paper demonstrates that greater hospital competition is significantly associated with increased EVAR adoption at a time when diffusion of this technology had just passed its tipping point. Hospital competition does not influence post-AAA repair outcomes. These results suggest that adoption of novel vascular technology is not solely driven by clinical indications, but may also be influenced by market forces.

These findings provide insight into adoption of medical technology in general. These results may help guide future healthcare policy designed to limit growing costs associated with technology development.

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TABLES AND FIGURES

Table 1. Characteristics of EVAR vs. open AAA repair patients

Variable	**Weighted frequency (S.E.)**		
	TOTAL (Weighted N=21,600)	**EVAR** (Weighted N=10,480)	**OPEN** (Weighted N=11,120)
Age in years (mean)	72.64 (±0.12)	73.55 (±0.20)	71.59 (±0.17)
Race:			
White	86.65 (±0.60)	87.03 (±0.88)	86.44 (±0.87)
Black	3.15 (±0.31)	2.81 (±0.43)	3.33 (±0.46)
Hispanic	4.18 (±0.35)	3.90 (±0.51)	4.43 (±0.52)
Asian/Pacific Islander	2.31 (±0.27)	2.41 (±0.41)	2.30 (±0.39)
Native American	0.06 (±0.05)	0.08 (±0.08)	0.06 (±0.06)
Other	3.65 (±0.03)	3.77 (±0.48)	3.44 (±0.45)
Female gender:	20.04 (±0.51)	16.66 (±0.74)	23.70 (±0.68)
Median income by zip code:			
Q1 (lowest)	18.14 (±0.56)	17.93 (±0.82)	18.15 (±0.80)
Q2	26.35 (±0.64)	26.13 (±0.95)	26.36 (±0.91)
Q3	29.76 (±0.67)	28.95 (±0.98)	30.51 (±0.97)
Q4 (highest)	25.75 (±0.63)	26.99 (±0.95)	24.98 (±0.89)
Primary payer:			
Medicare	78.49 (±0.60)	80.86 (±0.84)	76.49 (±0.88)
Medicaid	1.31 (±0.17)	1.11 (±0.23)	1.45 (±0.25)
Private including HMO	18.36 (±0.56)	16.12 (±0.79)	20.18 (±0.83)
Self pay	0.48 (±0.10)	0.29 (±0.11)	0.66 (±0.17)
No charge	0.10 (±0.04)	0.09 (±0.06)	0.11 (±0.07)
Other	1.26 (±0.16)	1.48 (±0.26)	1.10 (±0.21)
Patient county of residence:			

Large metropolitan	55.93 (±0.66)	57.26 (±1.02)	55.20 (±0.98)
Small metropolitan	26.37 (±0.61)	25.72 (±0.91)	26.93 (±0.89)
Micropolitan	9.71 (±0.40)	9.99 (±0.62)	9.25 (±0.58)
Other	7.99 (±0.38)	7.03 (±0.54)	8.62 (±0.57)
Co-morbidity			
Congestive heart failure	0.16 (±0.01)	0.05 (±0.03)	0.27 (±0.11)
Valvular disease	0.11 (±0.06)	0.09 (±0.06)	0.13 (±0.07)
Pulmonary circulation disorders	0.05 (±0.03)	0	0.06 (±0.04)
Peripheral vascular disorders	34.03 (±0.84)	31.72 (±1.04)	35.30 (±1.21)
Hypertension	63.22 (±0.71)	64.09 (±1.03)	62.86 (±1.01)
Paralysis	1.10 (±0.12)	1.24 (±0.20)	1.02 (±0.18)
Neurological disorders	2.25 (±0.22)	2.20 (±0.31)	2.34 (±0.32)
Chronic pulmonary disease	32.71 (±0.79)	29.88 (±0.92)	37.07 (±1.06)
Diabetes mellitus, uncomplicated	11.49 (±0.43)	13.45 (±0.68)	10.19 (±0.52)
Diabetes mellitus with chronic complications	0.74 (±0.10)	0.68 (±0.14)	0.89 (±0.16)
Hypothyroidism	5.36 (±0.34)	5.26 (±0.48)	5.47 (±0.48)
Renal failure	3.90 (±0.25)	2.74 (±0.30)	4.97 (±0.42)
Liver disease	1.09 (±0.15)	1.13 (±0.23)	1.07 (±0.21)
Peptic ulcer disease without bleeding	0.02 (±0.02)	0.02 (±0.02)	0
Lymphoma	0.49 (±0.08)	0.66 (±0.14)	0.39 (±0.11)
Metastatic cancer	0.46 (±0.07)	0.69 (±0.14)	0.32 (±0.10)
Solid tumor without metastases	2.32 (±0.19)	3.14 (±0.33)	1.72 (±0.21)
Rheumatoid arthritis/collagen vascular diseases	1.48 (±0.18)	1.41 (±0.26)	1.51 (±0.25)
Coagulopathy	5.70 (±0.41)	2.38 (±0.37)	8.74 (±0.66)
Obesity	4.55 (±0.30)	4.50 (±0.45)	4.74 (±0.44)
Weight loss	1.56 (±0.20)	0.44 (±0.12)	2.31 (±0.31)
Fluid and electrolyte disorders	13.65 (±0.62)	6.09 (±0.52)	21.06 (±0.96)
Chronic blood loss anemia	1.02 (±0.15)	0.64 (±.017)	1.41 (±0.22)
Deficiency anemias	7.33 (±0.46)	5.72 (±0.58)	9.48 (±0.70)
Alcohol abuse	1.89 (±0.20)	1.39 (±0.28)	2.48 (±0.29)
Drug abuse	0.18 (±0.06)	0.10 (±0.07)	0.28 (±0.11)
Psychoses	1.03 (±0.12)	0.69 (±0.14)	1.48 (±0.20)
Depression	2.33 (±0.22)	1.96 (±0.30)	2.50 (±0.33)

Died during hospitalization	2.96 (±0.22)	0.95 (±0.17)	4.40 (±0.38)
Length of stay (mean)	6.66 (±0.15)	3.54 (±0.13)	9.08 (±0.14)
Elective admission status:	81.78 (±1.23)	88.33 (±1.60)	80.85 (±1.14)

Table 2. Hospital characteristics for EVAR vs. OPEN AAA repair patients

Variable	**Weighted frequency (S.E.)**		
	TOTAL **(**Weighted N=21,600)	**EVAR** (Weighted N=10,480)	**OPEN** (Weighted N=11,120)
Hospital location:			
Urban	94.11 (±0.01)	95.05 (±0.35)	93.44 (±0.33)
Rural	5.89 (±0.01)	4.95 (±0.35)	6.56 (±0.33)
Hospital teaching status:			
Teaching	55.57 (±2.80)	61.01 (±3.88)	53.75 (±2.57)
Non-teaching	44.43 (±2.80)	38.99 (±3.88)	46.25 (±2.57)
Hospital bed size:			
Small	4.66 (±0.01)	3.82 (±0.27)	5.36 (±0.25)
Medium	22.15 (±0.01)	19.25 (±0.61)	25.06 (±0.58)
Large	73.19 (±0.01)	76.93 (±0.64)	69.58 (±0.61)
Hospital control:			
Government or private, collapsed category	67.87 (±2.57)	67.98 (±3.66)	66.10 (±2.39)
Government, nonfederal, public	3.06 (±0.82)	2.67 (±0.90)	3.55 (±0.96)
Private, non-profit, voluntary	20.59 (±2.29)	22.77 (±3.31)	19.45 (±1.95)
Private, investor-owned	6.07 (±0.91)	5.03 (±1.36)	7.59 (±1.08)
Private, collapsed category	2.40 (±0.84)	1.54 (±0.71)	3.31 (±1.14)
Geographic region:			
Northeast	21.92 (±3.00)	23.21 (±4.37)	21.04 (±2.41)
Midwest	24.37 (±2.48)	21.73 (±3.46)	26.79 (±2.20)
South	37.02 (±2.66)	37.62 (±3.78)	36.13 (±2.35)

West	16.69 (±1.95)	17.45 (±3.08)	16.04 (±1.40)
Hospital market characteristics (means):			
HHI in market defined by variable radius (90%)	0.16 (±0.01)	0.15 (±0.01)	0.19 (±0.01)
State Level Data:			
State health expenditures per capita (2004) in $	5,207 (±4.14)	5,172 (±9.16)	5,241 (±8.43)
State hospital adjusted expenses per inpatient day in $	1,444 (±2.03)	1,449 (±4.07)	1,441 (±4.02)
Total number of paid malpractice claims per state	705.48 (±44.91)	789.06 (±61.37)	667.93 (±36.79)
Average claims ($) paid per state	283,033 (±1,100)	278,906 (±1,783)	287,095 (±1,752)
Total number of hospitals per state	164.04 (±1..17)	175.21 (±1.99)	154.31 (±1.87)
Average number of vascular surgeons per 100,000 per state	0.72 (±0.01)	0.71 (±0.38)	0.73 (±0.38)
Vascular Volume per Hospital			
Vascular volume per hospital estimated by total AAA repairs	48.66 (±6.29)	59.63 (±7.94)	41.26 (±4.79)

Table 3. Bivariable analysis for outcome of EVAR vs. open AAA repair

Variable	**Odds Ratio**	**95% CI**	**P Value**
Age in years (mean)	1.031	1.024, 1.039	<0.0001
Race:			
White	Reference		
Black	0.934	0.639, 1.364	0.7228
Hispanic	0.870	0.599, 1.262	0.4620
Asian/Pacific Islander	1.042	0.615, 1.765	0.8787
Native American	1.253	0.078, 20.213	0.8737
Other	0.937	0.300, 2.929	0.9114
Missing 23.13%			
Female gender:	0.633	0.564, 0.710	<0.0001
Median income by zip code:			
Q1	0.884	0.704, 1.109	0.2867
Q2	0.853	0.678, 1.073	0.1749
Q3	0.865	0.690, 1.086	0.2124
Q4	Reference		
Primary payer:			
Medicare	Reference		
Medicaid	0.800	0.524, 1.219	0.2985
Private including HMO	0.744	0.639, 0.867	0.0001
Self-pay	0.718	0.378, 1.364	0.3121
No charge	1.198	0.297, 4.829	0.7993
Other	1.173	0.696, 1.977	0.5498
Patient county of residence:			
Large metropolitan	Reference		
Small metropolitan	0.823	0.641, 1.057	0.1267
Micropolitan	0.817	0.626, 1.066	0.1366
Other	0.735	0.553, 0.977	0.0339
Co-morbidity			
Congestive heart failure	0.041	0.006, 0.284	0.0012
Valvular disease	0.491	0.146, 1.657	0.2519
Peripheral vascular disorders	0.759	0.671, 0.857	<0.0001
Hypertension	1.082	0.962, 1.218	0.1906
Paralysis	1.182	0.751, 1.862	0.4691
Neurological disorders	1.071	0.807, 1.421	0.6334

Chronic pulmonary disease	0.724	0.656, 0.800	<0.0001
Diabetes mellitus, uncomplicated	1.335	1.158, 1.540	<0.0001
Diabetes mellitus with chronic complications	0.806	0.472, 1.378	0.4306
Hypothyroidism	1.037	0.831, 1.295	0.7480
Renal failure	0.519	0.388, 0.695	<0.0001
Liver disease	1.172	0.686, 2.000	0.5616
Lymphoma	1.835	0.927, 3.634	0.0814
Metastatic cancer	2.345	1.124, 4.891	0.0230
Solid tumor without metastases	1.845	1.360, 2.502	<0.0001
Rheumatoid arthritis/collagen vascular diseases	1.085	0.743, 1.583	0.6743
Coagulopathy	0.249	0.180, 0.343	<0.0001
Obesity	0.942	0.727, 1.221	0.6536
Weight loss	0.165	0.097, 0.282	<0.0001
Fluid and electrolyte disorders	0.244	0.201, 0.296	<0.0001
Chronic blood loss anemia	0.449	0.260, 0.774	0.0040
Deficiency anemias	0.602	0.476, 0.761	<0.0001
Alcohol abuse	0.565	0.361, 0.884	0.0125
Drug abuse	0.398	0.077, 2.062	0.2723
Psychoses	0.497	0.312, 0.791	0.0032
Depression	0.967	0.704, 1.327	0.8347
Elective admission status	1.845	1.447, 2.352	<0.0001
Urban hospital location	1.779	1.051, 3.009	0.0318
Teaching hospital	1.345	1.036, 1.747	0.0262
Hospital bed size:			
Small	0.982	0.487, 1.979	0.9591
Medium	0.607	0.439, 0.839	0.0025
Large	Reference		
Hospital control:			
Government or private, collapsed category	Reference		
Government, nonfederal, public	0.728	0.447, 1.186	0.2026
Private, non-profit,	1.118	0.834, 1.501	0.4553

voluntary			
Private, investor-owned	0.671	0.379, 1.189	0.1718
Private, collapsed category	0.459	0.246, 0.858	0.0146
Geographic region:			
Northeast	Reference		
Midwest	0.730	0.463, 1.151	0.1762
South	0.923	0.618, 1.380	0.6977
West	0.975	0.602, 1.580	0.9177
Hospital market characteristics:			
HHI in market defined by variable radius (90%)	0.192	0.077, 0.478	0.0004
Vascular volume per hospital estimated by total AAA procedures in 2003	1.009	1.003, 1.015	0.0020

Table 4. Multivariable analysis for outcome of EVAR adoption.

Variable	Odds Ratio	95% CI	P Value
Mean age in years (Per 1 year)	1.041	1.032, 1.051	<0.0001
Female (vs. male) gender:	0.613	0.518, 0.725	<0.0001
Co-morbidity (yes vs. no)			
Congestive Heart Failure	0.073	0.008, 0.704	0.0236
Peripheral vascular disorders	0.732	0.626, 0.855	<0.0001
Diabetes mellitus, uncomplicated	1.479	1.240, 1.765	<0.0001
Solid tumor without metastases	1.883	1.287, 2.755	0.0011
Coagulopathy	0.284	0.191, 0.422	<0.0001
Weight loss	0.364	0.185, 0.717	0.0035
Fluid and electrolyte disorders	0.275	0.215, 0.352	<0.0001
Deficiency anemias	0.602	0.467, 0.776	<0.0001
Admission status:			
Elective (vs. emergent)	1.704	1.272, 2.282	0.0004
Hospital location:			
Urban (vs. rural)	0.582	0.288, 1.179	0.1330
Hospital control:			
Government or private, collapsed category	Reference		
Government, nonfederal, public	0.582	0.288, 1.179	0.5367
Private, non-profit, voluntary	0.816	0.428, 1.555	0.0281
Private, investor-owned	1.071	0.571, 2.012	0.8299
Private, collapsed category	0.494	0.203, 1.201	0.1198
Hospital market characteristics:			
HHI in market defined by variable radius (90%) (per 0.1 decrease in HHI)	1.127		

		1.102, 1.154	0.0127
Vascular Volume per Hospital			
Vascular volume per hospital estimated by total AAA procedures in 2003 (Per 1 additional procedure)	1.008	1.005, 1.011	<0.0001

Table 5. Covariate balancing between EVAR and open-AAA repair patients after propensity-score inverse weighting

Variable	Weighted frequency (S.E.)			
	EVAR (Weighted N=16,383)	**OPEN** (Weighted N=18,916)	**Unadjusted P value**	**Propensity-score adjusted P value**
Age in years (mean)	73.55 (±0.20)	71.46 (±0.16)	<0.0001	0.8017
Female gender:	16.66 (±0.74)	24.01 (±0.66)	<0.0001	0.5505
Primary payer:				
Medicare	80.99 (±0.97)	76.55 (±0.89)	Reference	Reference
Medicaid	1.11 (±0.20)	1.32 (±0.19)	0.2985	0.8361
Private including HMO	16.10 (±0.91)	20.45 (±0.84)	0.0001	0.9255
Self-pay	0.48 (±0.14)	0.63 (±0.13)	0.3121	0.7636
No charge	0.11 (±0.06)	0.09 (±0.5)	0.7993	0.8552
Other	1.20 (±0.25)	0.97 (±0.21)	0.5498	0.3445
Co-morbidity				
Congestive heart failure	0.03 (±0.03)	0.80 (±0.15)	0.0012	0.0375
Peripheral vascular disorders	31.72 (±1.04)	37.97 (±1.17)	<0.0001	0.3251
Chronic pulmonary disease	29.88 (±0.92)	37.05 (±1.02)	<0.0001	0.6471
Diabetes mellitus, uncomplicated	13.45 (±0.68)	10.43 (±0.51)	<0.0001	0.2613
Renal failure	2.74 (±0.30)	5.15 (±0.43)	<0.0001	0.1400
Lymphoma	0.66 (±0.14)	0.36 (±0.10)	0.0814	0.9708
Metastatic cancer	0.69 (±0.14)	0.30 (±0.09)	0.0230	0.8001
Solid tumor without metastases	3.14 (±0.33)	1.73 (±0.21)	<0.0001	0.9014
Coagulopathy	2.38 (±0.37)	8.92 (±0.63)	<0.0001	0.1347
Weight loss	0.44 (±0.12)	2.62 (±0.33)	<0.0001	0.6525
Fluid and electrolyte disorders	6.09 (±0.52)	21.03 (±0.96)	<0.0001	0.1501

Chronic blood loss anemia	0.64 (±0.17)	1.41 (±0.21)	0.0040	0.4219
Deficiency anemias	5.72 (±0.58)	9.16 (±0.65)	<0.0001	0.5411
Alcohol abuse	1.39 (±0.28)	2.44 (±0.28)	0.0125	0.8940
Psychoses	0.69 (±0.14)	1.38 (±0.19)	0.0032	0.1596
Admission status:				
Elective	88.33 (±1.60)	80.40 (±1.15)	<0.0001	0.7870
Hospital control:				
Government or private, collapsed category	67.98 (±3.66)	66.09 (±2.37)	Reference	Reference
Government, nonfederal, public	2.67 (±0.90)	3.56 (±0.92)	0.2026	0.7986
Private, non-profit, voluntary	22.77 (±3.31)	19.79 (±1.98)	0.4553	0.4181
Private, investor-owned	5.03 (±1.36)	7.29 (±1.02)	0.1718	0.6679
Private, collapsed category	1.54 (±0.71)	3.27 (±1.09)	0.0146	0.6887
Hospital location:				
Urban	95.83 (±1.30)	92.82 (±1.32)	0.0318	0.9562
Hospital teaching status:				
Teaching	61.01 (±3.88)	53.78 (±2.54)	0.0262	0.4749
Vascular Volume per Hospital				
Vascular volume per hospital estimated by total AAA repairs	59.63 (±7.94)	41.72 (±4.98)	0.0020	0.5132

Figure 1: Sample calculation of the Herfindahl Hirschman Index.

Herfindahl-Hirschman Index

$$H = \sum_{i=1}^{N} s_i^2$$

N **= # hospitals in market**
S_i = market share of hospital

Eg. Market with 2 firms each with 50% market share:

HHI = $0.5^2 + 0.5^2 = ½$

Market with 4 firms each with 25% market share:

HHI = $0.25^2 + 0.25^2 + 0.25^2 + 0.25^2 = ¼$

Figure 2: EVAR adoption trends between 2001 and 2007 for non-ruptured AAA repairs.

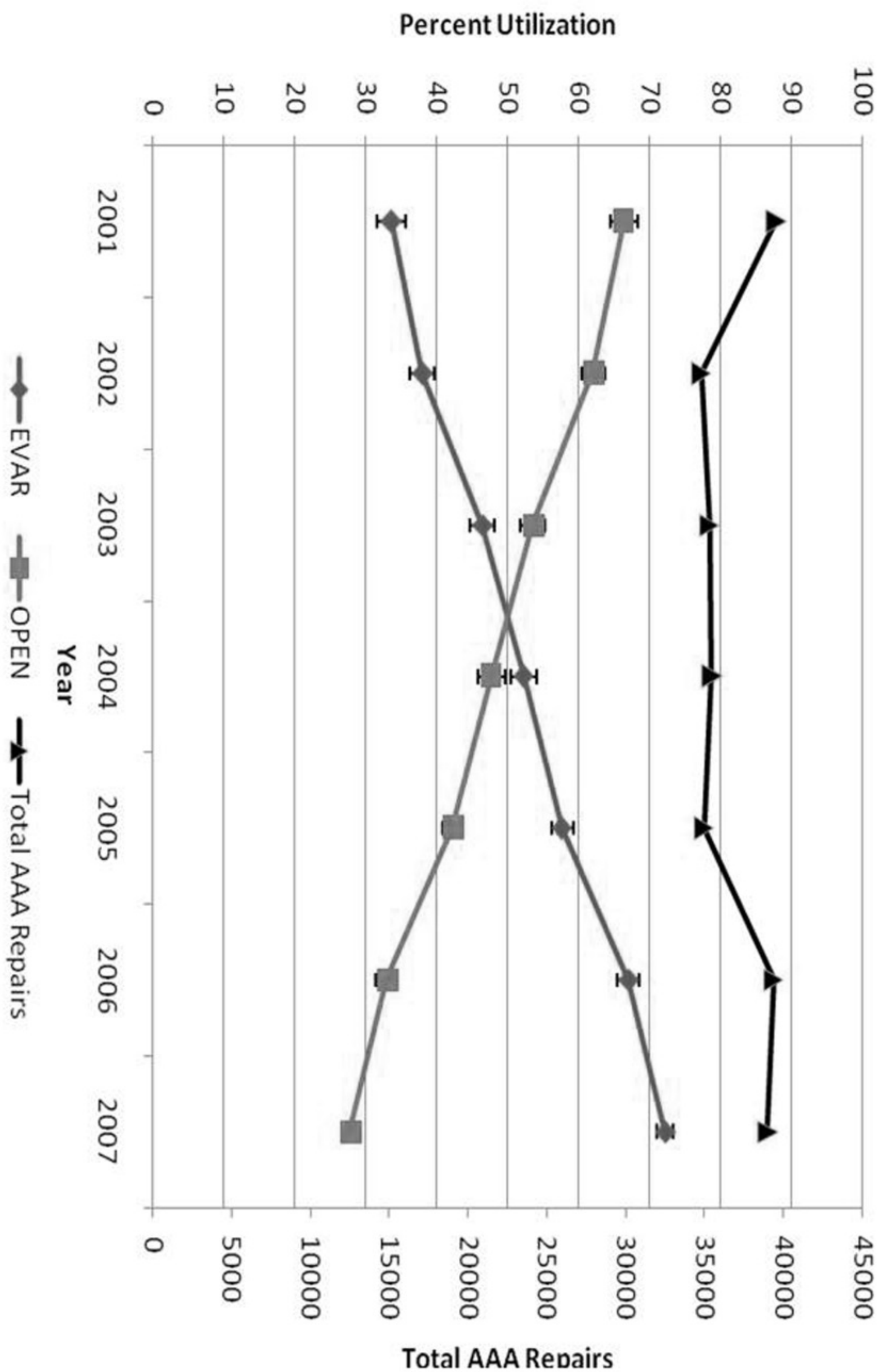

Figure 3: Geographic variation in percent EVAR utilization across the US (2001-2007).